THE ANTENNA LABORATORY

UNPUBLISHED PRELIMINARY DATA

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RESEARCH ACTIVITIES in ---

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FACILITY FORM 602

N65 16426 (ACCESSION NUMBER)	(THRU)
10 (PAGES)	/ (CODE)
CR-50177 (NASA CR OR TMX OR AD NUMBER)	14 (CATEGORY)

GPO PRICE $ ____

OTS PRICE(S) $ ____

Hard copy (HC) 1.00

Microfiche (MF) .50

Semi-Annual Report

1 September 1962 to 28 February 1963

Receiver Techniques and Detectors for Use at Millimeter and Submillimeter Wavelengths

Grant Number NsG-74-60

1093-14 — 1 March 1963

Prepared for: National Aeronautics and Space Administration Washington 25, D.C.

Department of ELECTRICAL ENGINEERING

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[redacted]

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION
Columbus, Ohio

10 p.

REPORT 1093-14

[redacted]

REPORT
by
THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS 12, OHIO

Sponsor	National Aeronautics and Space Administration 1520 H Street Northwest Washington 25, D.C.
Grant Number	NsG-74-60
Investigation of	Receiver Techniques and Detectors for Use at Millimeter and Submillimeter Wavelengths
Subject of Report	Semi-Annual Report 1 September 1962 to 28 February 1963
Submitted by	Antenna Laboratory Department of Electrical Engineering
Date	1 March 1963

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SEMI-ANNUAL REPORT

I. INTRODUCTION

The purpose of the present research program is to investigate various detection and receiver techniques, both conventional and unconventional, in the millimeter and submillimeter wavelength regions. Particular emphasis is placed upon the investigation of those techniques that are pertinent to future interplanetary radio-astronomy and communications applications.

Most of our recent research has been concentrated in two major areas: (a) the design and construction of a submillimeter radiometer, and (b) the experimental studies of submillimeter maser materials. Each of these areas has already produced valuable research results. Moreover, we have also gained the unique experience and background in submillimeter techniques that will enable us to investigate many engineering and scientific problems in this wavelength in the future.

II. SUMMARY OF RESEARCH RESULTS THROUGH FEBRUARY 1963

A. The Submillimeter Radiometer

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1. Based upon the analysis made in Report 1093-9, a submillimeter radiometer has been designed using a Michelson interferometer as the modulator, a wire mesh as the beam splitter, an Archimedes' cam as the driver of the linear reciprocating motion, and a Golay cell as the detector. Electronic, optical and mechanical components are being purchased and constructed. Figure 1 shows the schematic diagram of the preliminary design of this radiometer. Preliminary experiments have been performed on an existing spectrometer using a commercial black-body source. These results showed a minimum detectable temperature of 12°K, which agrees approximately with our analysis. Table 1 shows the theoretically calculated sensitivity and the measured sensitivity using the existing spectrometer to simulate the radiometer under construction. It is expected that the entire radiometer except the antenna will be assembled and tested in the spring of 1963. A paper on this radiometer was presented at the millimeter and submillimeter conference at Orlando, Florida on January 10, 1963, and a paper on submillimeter radiometry is being prepared for publication.

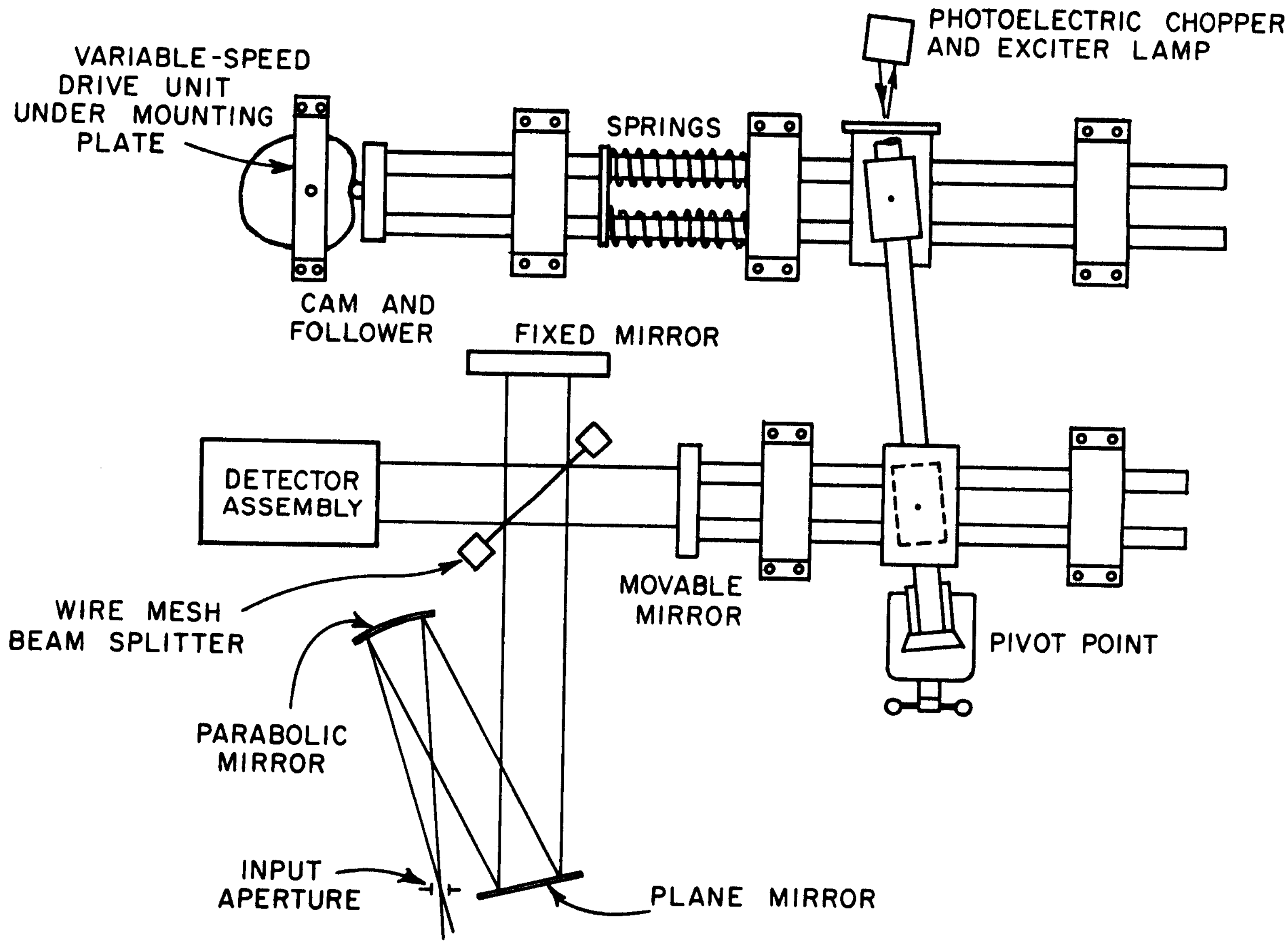

Fig. 1. Schematic diagram of the preliminary design of radiometer.

Detector	P_f (estimated)	$\Delta\nu$	ν	S	F	Δf_P $(1/\tau)$	ΔT_{min} (calculated)	ΔT_{min} (observed)
Ge bolometer	10^{-12} watt/sec	2.2 cm^{-1}	28.5 cm^{-1}	2.36 cm^2	4.4	0.2 sec^{-1}	0.23° K	
Carbon bolometer	10^{-10} watt/sec	2.2 cm^{-1}	28.5 cm^{-1}	2.36 cm^2	4.4	0.2 sec^{-1}	2.3° K	
In Sb	10^{-10} watt/sec	2.2 cm^{-1}	28.5 cm^{-1}	2.36 cm^2	4.4	0.2 sec^{-1}	2.3° K	
Golay	10^{-9} watt/sec	3.3 cm^{-1}	22 cm^{-1} (.465 mm)	2 cm^2	4.0	0.04 sec^{-1}	7° K	12° K
	10^{-9} watt/sec	2.5 cm^{-1}	16.4 cm^{-1} (.611 mm)	2 cm^2	4.0	0.04 sec^{-1}	15° K	26° K

TABLE 1
Theoretically calculated sensitivity and measured sensitivity using the existing spectrometer to simulate the radiometer under construction.

2. An attempt is being made to construct a carbon bolometer at $1.5^{\circ}K$. Such a bolometer would have a detection sensitivity about one order of magnitude better than the Golay cell. So far we have constructed most of the experimental apparatus including light pipes, bolometer element, and optics. But experimental difficulties were encountered in our attempt to bring the bolometer below $4^{\circ}K$. Extra radiation shields and another helium dewar are in the process of being constructed to correct this condition. Testing of the bolometer element with far-infrared radiation will be performed as soon as possible. It is hoped that such a highly sensitive detector can be used with the radiometer to increase its sensitivity.

B. The Submillimeter Maser Studies

1. Precise measurement of the dielectric constants, the dispersion, and the absorption coefficient of the laser materials $CaWO_4$ and MgO has been completed. Two papers (Reports 1093-11 and 1093-12) on the measurements of the properties of laser crystals at submillimeter wavelengths were presented at the Symposium on Lasers and Applications on 8 November 1962, at The Ohio State University and at the Third International Symposium on Quantum Electronics on February 12, 1963, in Paris, France. A dissertation concerning these host lattice properties has been published as Technical Report 1093-13.

2. For want of single crystal materials, pressed powdered samples of Ho_2O_3, Er_2O_3, etc., have been successfully prepared at The Ohio State University. Preliminary measurements of these pressed powdered samples indicate that the samples are semi-transparent at submillimeter wavelengths. As with single crystals, an increase of transparency at $100^{\circ}K$ over the degree of transparency at room temperature was obtained. Because of the scattering loss, it was decided that these samples were good only for initial measurement of the submillimeter energy levels. If one wants to construct a laser, single crystals must be made. Subsequent measurements of the energy levels of these samples at $100^{\circ}K$ were made, but they were not successful. In comparing these unsuccessful results with the newly published results of the magnetic transitions in garnets measured by Tinkham, we attributed these failures to the fact that one really needs to go to liquid-helium temperatures in order to obtain a successful measurement of submillimeter energy levels. Therefore, cold windows and radiation shields are presently being installed on the liquid-helium dewar in an attempt to bring the samples to liquid-helium temperatures. Previous measurements indicated that the temperature of the sample would be approximately $50^{\circ}K$ without the use of special radiation windows. Measurements of absorption spectra and their

oscillator strengths will be resumed as soon as we can successfully bring the temperature of the sample down below 10°K. It is hoped that preliminary data on the oscillator strengths would show us the chance of success for the development of a submillimeter maser.

We have also made a preliminary calculation of the resonance absorption coefficient and population inversion needed to achieve maser action in these host lattices. These considerations are given in Technical Report 1093-12.

C. Miscellaneous Results

1. A modification of the bibliographical search on laser materials has been made to include more complete data. The modified report is in the process of being printed and will be issued in the current grant period.

2. Experimental accuracy of the cross-relaxation data has been improved. Modifications mentioned in the last semi-annual report have been carried out. A report (and a thesis) on this study are in process.

III. FUTURE RESEARCH PLANS

Basically, we would like to continue our dual program of research on submillimeter radiometers and submillimeter lasers (i.e., quantum electronics techniques in general).

1. We propose to assemble the submillimeter radiometer as it has been designed and to test its sensitivity using the laboratory black-body source. Simultaneously, we propose to develop another detector such as the carbon bolometer (or germanium bolometer) so that the sensitivity of the submillimeter radiometer may be increased to the desired theoretical limit (i.e., the order of 2 degrees Kelvin or less). Once this radiometer is completed, we propose to install it in some low-humidity location and observe solar radiation. This radiometer will also be supplemented by a Fabry-Perot interferometer or a grating-monochromator, if time and budget permit, to convert it into a general submillimeter receiver.

2. We propose to continue the measurement of the energy levels and oscillator strength of the laser materials at liquid-helium temperature in submillimeter wavelengths with the hope that a submillimeter laser may be developed. The pressed powdered sample and single crystals

of aluminum garnet would be tried first. Based upon these data, we could then partially assess the possibility of the development of a submillimeter maser. If the result is encouraging we could also try to optically pump the crystal, using available lasers, in order to observe various relaxation and maser effects. Regardless of whether a submillimeter laser is successful or not, we feel that the fundamental information obtained by the direct measurement of absorption spectra in the far-infrared and the submillimeter region would be a very valuable contribution to infrared technology. If the development of the submillimeter laser does not appear to be possible after the initial data are obtained, the techniques and the information gained could be used immediately to investigate the mixing of laser radiation in crystals for amplification and generation of submillimeter waves.

3. Since the harmonic generation and mixing of optical laser radiations have been so successfully carried out in the visible light wavelengths, and since the Antenna Laboratory already established a complete laser research facility, we propose that the generation of submillimeter radiation by the mixing of two lasers be explored in this project. The successfulness of such a program depends upon: (a) the measurement and the finding of a material that will satisfy the conditions of index matching, (b) the ability of generating strong radiation by means of a good Q-switched laser, and (c) the capability of detecting very weak submillimeter radiation. We have Q-switched lasers now, but we need to find a proper material. We will depend upon the progress in our detector studies to give us a sensitive detector unless funds (approximately $8,000) are allocated to buy a detector from a commercial source. In other words, the progress in this phase of the program would depend upon funding.

Fundamentally, we propose to expand the scientific manpower effort during the next renewal period over the present period, and an associated increase of funding for materials, equipment, and supplies is strongly recommended. (Particularly needed is a detector with fast response such as the indium-antimonide photodetector manufactured by Mullard.) In addition, if the radiometer is successful we would like (a) to use it outside the Columbus, Ohio, region in a low-humidity location for solar and lunar observations, and (b) to expand it so that it could serve as a general-purpose high-resolution receiver. The details of this proposed budget have already been presented to NASA in our "Proposal for One-Year Renewal of Grant NsG-74-60" dated 7 January 1963.